

§6. Efficient Scenario for Establishing Transport Barrier Using Hysteresis in CHS

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It has been known from CHS experiments to date that three branches of potential profile should exist in a low density regime of the ECR-heating related plasma. This proposition can be confirmed by making a Lissajous diagram on potential evolution as a function of the line-averaged density. Examples are provided in the following discharges where the ECR-heating of $P_{\text{ECRH}} \sim 100\text{kW}$ is applied to the target plasmas sustained with NBI-heating.

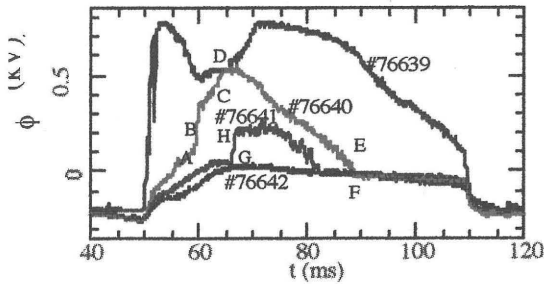


FIG.1. Evolution of the potential and the line-averaged density in plasmas with a combined heating of ECR (100kW)+NBI (800kW). The waveforms of the central potential.)

Figure 1 shows three examples of time evolution of the central potential during the combined heating phase ($50\text{ms} < t < 108\text{ms}$) in deuterium plasmas. The initial densities of the plasmas are $n_e = 0.2 \times 10^{13} \text{ cm}^{-3}$ (#76639), $n_e = 0.6 \times 10^{13} \text{ cm}^{-3}$ (#76640), $n_e = 0.8 \times 10^{13} \text{ cm}^{-3}$ (#76641) and $n_e = 0.9 \times 10^{13} \text{ cm}^{-3}$ (#76642). After the ECR-heating of $P_{\text{ECRH}} \sim 100 \text{ kW}$ is turned on, a rapid increase in potential and the following back-and-forth transitions, seemingly a pulse, are observed in the discharge with the lowest density (#76639; the green line). In the other two shots (the red and blue lines), the potential gradually increases and transitions to upper potential states occur in the time scale of a few dozen microseconds. Then the potential gradually decreases. In the lowest density discharge (#76639), the line-averaged density monotonically increases after launch of ECR-heating, while the other two shots show an increase in the density after an initial decrease.

Figure 2 shows five Lissajous traces including the above three cases; the initial densities of the other discharges are $n_e = 0.9 \times 10^{13} \text{ cm}^{-3}$ and $n_e = 1.0 \times 10^{13} \text{ cm}^{-3}$.

These Lissajous traces fall on curves to indicate four branches; three branches in the combined heating phase of ECR+NBI and one for the NBI-heating phase. Low, middle and high branches in Fig. 2 are termed here, hill, dome and bell, respectively.

As for the Lissajous traces of shot #76640, the plasma status evolves as a loop of A-B-C-D-E-F during the combined heating phase. This loop shows a *hysteresis* in potential on the density evolution. Initially after launch of ECR-heating, the potential increases through point-F along the hill-branch. After that, several transitions happen; at point-A (from the hill- to the dome-branch), point-C (from the dome-branch to the bell-branch) point-E (back transition from the dome- to the hill-branch). Also hysteresis and transition from the hill- to the dome-branch (from point H to G) are seen in the Lissajous trace of shot #76641.

Using the hysteresis, transition into higher potential states (dome or bell), or formation of the internal transport barrier is more easily realized in a lower density region. The realization probability of dome and bell-branches is actually larger in the lower density region. The scaling of energy confinement time for stellarators shows favorable dependence on line-averaged density. It is expected, accordingly, that higher density should be consistent with higher stored energy under the condition that the plasma potential (or other parameters) changes along a curve of an identical branch. Therefore, it is an effective route for achieving higher plasma performance to increase the density after making transition from hill-branch to dome-branch (or bell-branch) at a low density.

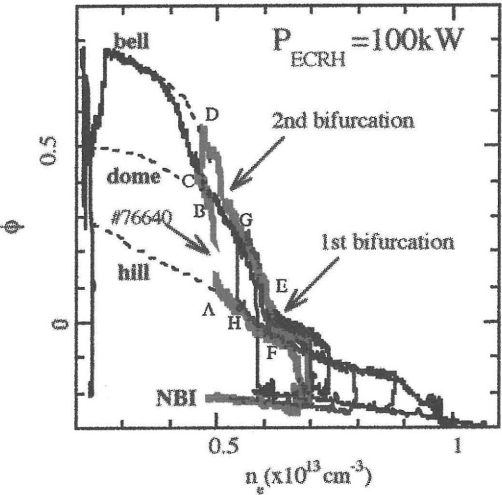


Fig. 2. The Lissajous lines made of the central potential and the line-averaged electron density. A clear hysteresis is seen.

Reference

- 1) Fujisawa, A. et al., Nuclear Fusion **41** 575(2001).